BASEBAND PROCESSING METHOD BASED ON SMART ANTENNA AND INTERFERENCE CANCELLATION

Cross Reference to Related Application

This is a continuation application of PCT/CN00/00169 filed June 22, 2000, incorporated herein by reference in its entirety.

Field of the Technology

The present invention relates generally to interference signal cancellation technology used in base stations of wireless communication systems having smart antennas, and more particularly to a baseband processing method based on smart antenna and interference cancellation.

Background of the Invention

In modern wireless communication systems, especially in CDMA (Code Division Multiple Access) wireless communication systems, in order to increase system capacity, system sensitivity and communication distances with lower emission power, smart antennas are generally used.

The Chinese patent named "Time Division Duplex Synchronous Code Division Multiple Access Wireless Communication System with Smart Antenna" (CN 97 1 04039.7) discloses a base station structure for a wireless communication system with smart antennas. The base station includes an antenna array consisting of one or more antenna units, corresponding radio frequency feeder cables and a set of coherent radio frequency transceivers. Each antenna unit receives signals from user terminals. The antenna units direct the space characteristic vectors and directions of arrival (DOA) of the signals to a baseband processor. The processor then implements receiving antenna beam forming using a corresponding algorithm. Among them, any antenna unit, corresponding feeder cable and coherent radio frequency transceiver together is called a link. By using weight getting from the up link receiving beam forming of each link in the down link transmitting beam forming, the entire functionality of smart antennas can be implemented, under symmetrical wave propagation conditions.

A primary aspect of modern wireless communication systems is mobile communication. Mobile communication works within a complex and variable environment (reference to ITU proposal M1225). Accordingly severe influences of time-varying and multipath propagation must be considered. The Chinese patent referenced above as well as many technical documents concerning beam forming algorithms of smart antennas conclude increased functionality will result with increased algorithm complexity. Nevertheless, under a mobile communication environment, beam forming must be completed in real time, and algorithm-completion time is at a microsecond level. As another limitation of modern microelectronic technology, digital signal processing (DSP) or application specific integrated circuits (ASIC) cannot implement highly complex real time processing within such short time periods. Faced with this conflict, within a mobile communication environment, simple and real time algorithms for smart antennas not only cannot solve the multipath propagation problem, but also cannot thoroughly solve system capacity problems of CDMA mobile communication systems.

Technologies such as the Rake receiver and Joint Detection or Multi User Detection have been widely studied for use in CDMA mobile communication systems in an attempt to solve the interference problems associated with multipath propagation. Nevertheless, neither the Rake receiver nor multiuser detection technology can be directly used in mobile communication systems with smart antennas. Multiuser detection technology processes the CDMA signals of multiple code channels, after channel estimation and matched filter, and all user data are solved at the same time using an inverse matrix. However smart antenna technology makes beam forming for each code channel separately, and so it is difficult to take advantage of the diversity provided by user multipath technology. Rake receiver technology composes user main multipath components, but it also destroys the phase relationship between antenna units of an antenna array. Another limitation of Rake receiver technology is that the user number is the same as the spread spectrum coefficient, which makes it impossible to work under full code channel circumstances.

There is a two-dimensional smart antenna technology, but it is in a research stage and its algorithm is immature and complex.

There is another method which processes multiuser detection after using smart antenna; but at this time as each code channel has been separated, processing must be separated for each code channel. As a result this technology not only cannot fully bring multiuser detection function into play, but it also greatly increases the complexity of baseband signal processing.

Summary of the Invention

In order to increase system capacity and provide better performance for CDMA wireless communication systems, it is necessary to provide a simple and real time interference cancellation method convenient for use in CDMA wireless communications based on smart antennas.

Therefore, an object of the invention is to provide a baseband processing method based on smart antenna and interference cancellation. By designing a new digital signal processing method, CDMA mobile communication systems or other wireless communication systems, which use the method, can use smart antennas and solve multipath propagation interference at the same time.

A further object of the invention is to provide a set of new digital signal processing methods, which can be used in CDMA mobile communication systems or other wireless communication systems, and can solve various multipath propagation interference problems while using smart antennas.

The invention of a baseband processing method based on smart antenna and interference cancellation comprises the steps of:

A. with a known user training sequence, taking sampled-data output signals from link antenna units and radio frequency transceivers of a communication system to make channel estimations, and then getting all users responses on all channels;

B. picking up useful symbolic level signals from the sampled-data output signals, based on the channel estimation, using smart antenna beam formation;

C. reconstructing signals with the useful symbolic level signals, and adding a scramble code, then getting chip level reconstructed signals;

D. subtracting the reconstructed signals from the sampled-data output signals; and

E. executing steps B to D repeatedly until recovering all user signals.

Step A is done by a channel estimation module, and the channel response includes a matrix, which is related to each user training sequence and is calculated and stored beforehand.

Step B includes: making a power estimation of the response for all users on all channels with a power estimation module, calculating all users main paths and multipath power distributions within a searching window; sending calculated power distributions to signal generators to generate signals, which includes: calculating each user's maximum peak value power position, storing this peak value power position in a power point and getting de-spread results of all signals at the power point with a smart antenna algorithm.

When calculating each user's maximum peak value power position, an adjustment parameter for synchronization is sent to a transmitting module of that user with the most powerful path not at the same point of other users and without synchronization with the base station.

Step B further comprises: sending the de-spread results to a signal/noise ratio estimation module simultaneously, estimating all users signal/noise ratios, executing steps C, D, E continuously for users with a low signal/noise ratio and outputting the signal results directly for users with a high signal/noise ratio.

Estimating the user signal/noise ratio comprises: calculating user power; deciding the user power greater than a certain field value as effective power; calculating the square difference for all signals with an effective power at their corresponding constellation map point; deciding those users with a low signal/noise ratio if their square difference is greater than a preset value, and those users with a high signal/noise ratio if their square difference is less than a preset value.

Step C reconstructs an original signal in a signal reconstructing module and calculates the components of all users' signals and multipath on each antenna unit.

Step D cancels interference in an interference cancellation module.

Step E is executed in a decision module, until the number of interference cancellation loops reaches a preset number, which is less than or equal to the length of a searching window, then stops interference cancellation and outputs the recovered signals.

Step E is executed in a decision module, until the signal/noise ratio of all signals is greater than a set field value, then stops interference cancellation and outputs recovered signals.

Step E executes steps B to D repeatedly with an at most repeated number equal to the length of the searching window.

It is essential to the invention that beam forming of every multipath within a searching window length is done for every channel, and useful signals are selected and accumulated so as to utilize the advantages of space diversity and time diversity. In this way even under conditions of severe multipath interference and white noise interference, better results can be achieved. The calculation volume of the method is limited and can be implemented with commercial chips such as digital signal processors (DSP) or field programmable gate arrays (FPGA).

The method of present invention is particularly useful for wireless communication systems of code division multiple access including time division duplex (TDD) and frequency division duplex (FDD).

Brief Description of the Drawings

Figure 1 is base station structure diagram of wireless communication with smart antenna.

Figure 2 is an implementing skeleton diagram of smart antenna and interference cancellation method.

Figure 3 is an implementing flow chart of smart antenna and interference cancellation method.

Detailed Description of the Invention

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the

scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

The present invention is useful with mobile communication systems having smart antennas and inference cancellation or wireless communication systems such as wireless user loop systems. Fig. 1 shows a base station structure of one such system. The base station includes *N* identical antenna units 201A, 201B, ..., 201i, ..., 201N; *N* substantially identical feeder cables 202A, 202B, ..., 202i, ..., 202N; N radio frequency transceivers 203A, 203B, ..., 203i, ..., 203N; and a baseband processor 204. All transceivers 203 use the same local oscillator 208 to guarantee that each radio frequency transceiver works in coherence. Each radio frequency transceiver includes Analog to Digital Converters (ADC) and Digital to Analog Converters (DAC), so that all baseband input and output for the radio frequency transceivers 203 are digital signals. The radio frequency transceivers are connected to the baseband processor by a high speed digital bus 209. In Fig. 1, block 100 shows the base station devices.

The invention only discusses interference cancellation of receiving signals in baseband processing as shown in Fig. 1, without considering transmitting signal processing. Smart antenna implementation and interference cancellation is performed in baseband processor 204.

As an example, assume that the CDMA wireless communication system has K designed channels, and the smart antenna system consists of N antenna units, N feeder cables and N radio frequency transceivers, i. e. N links. In each receiving link, after sampling by ADC in a radio transceiver, the output digital signals are $S_1(n), S_2(n), \ldots, S_i(n), \ldots, S_N(n)$, where n is the n^{th} chip. Taking the i^{th} receiving link as an example, after sampling its receiving signal by ADC in radio frequency transceiver 203i, the output digital signal is $S_i(n)$, which is the input signal for baseband processor 204. Baseband processor 204 includes channel estimation modules 210A, 210B, ..., 210i, ..., 210N, which correspond to N radio frequency transceivers 203A, 203B, ..., 203i, ..., 203N of N links, respectively, and smart antenna interference cancellation module 211. Output digital signals of N links $S_1(n), S_2(n), \ldots, S_i(n), \ldots, S_N(n)$ are sent to channel estimation modules 210A, 210B, ..., 210i, ..., 210N, respectively. The output digital signals are also sent to smart antenna interference cancellation module 211. Channel response

signals $\vec{h}_1, \vec{h}_2, \ldots \vec{h}_i, \ldots \vec{h}_N$ which correspond to the outputs of channel estimation modules 210A, 210B, …, 210i, …, 210N, respectively, are sent to smart antenna interference cancellation module 211. Smart antenna inference cancellation module 211 outputs synchronous adjustment parameter $S_s(K)$ to a down link transmitting module and outputs the interference cancellation result $S_{ca+1,k}(d)$ to a channel decode module, where $\vec{h}_i = [h_{i,1}, h_{i,2}, \ldots, h_{i,k}]$.

When $S_i(n)$ enters channel estimation module 210i, with a predetermined training sequence (Pilot or Midamble), K channels are estimated and K channels pulse response $h_{i,k}$ are calculated , where i is the i^{th} antenna unit and k is the k^{th} channel.

The specific processing procedure is as follows. Assuming that a k^{th} user's known training sequence is m_k, and the training sequence received from the i^{th} antenna is e_i, then the formula (1) below is used:

$$e_i(n) = \sum_{k=1}^{K}\sum_{w=1}^{W} m_k(n-w+1)h_{i,k}(w) + n_{oi} \qquad (1)$$

where n is the n^{th} chip, w is the length of the searching window and n_{oi} is white noise received from the i^{th} antenna. Formula (1) can be further rewritten as formula (2):

$$e_i = Gh_{i,k} + n_{oi} \qquad (2)$$

and then, channel estimation can be shown as formula (3):

$$h_{i,k} = (G^{*T}G)^{-1}G^{*T}e_i = M_{li} \qquad (3)$$

where M is a matrix, which only relates with every user training sequence and can be calculated and stored in advance, as channel estimation will be greatly increased when it is unnecessary to calculate it in real time.

According to the procedure above, the responses of all users in all channels can be calculated, respectively, and the results $h_{i,k}$ are inputted to a smart antenna inference cancellation module 211. After further processing, all user signals will be recovered.

Fig. 2 illustrates interference cancellation processing of a smart antenna interference cancellation module 211. First, a channel response $h_{i,k}$, calculated by channel estimation module 210i, is sent to a power estimation module 220 to estimate power. The main path

and multipath power distribution of K users (with K channels) in a searching window are calculated, as shown with formula (4):

$$power\_user_k(m) = \sum_{i=1}^{N} abs(h_{i,k}(m)) \qquad (4)$$

Then, the maximum peak power point of each user is calculated. If a user's most powerful path is not at the same point of the most powerful path of other users, then the user does not synchronize with the base station. The base station will inform the user in a down link channel to adjust in order to synchronize with other users. The adjustment parameter is $S_s(K)$ as noted above.

Then, a k^{th} user main path and multipath total power distribution in a searching window is calculated, as is shown with formula (5):

$$power\_abs(m) = \sum_{i=1}^{N}\sum_{k=1}^{K} abs(h_{i,k}(m)) \qquad (5)$$

where m is a point in the searching window, and the *power_abs* is sent to a signal generator 221 to generate a signal. At the same time, signals, sent to signal generator 221, also have channel response signals $\vec{h}_1, \vec{h}_2, \ldots \vec{h}_i, \ldots \vec{h}_N$ (vector), outputted by each channel estimation module 210A, 210B, ..., 210i, ..., 210N, respectively, and output digital signals $S_1(n), S_2(n), \ldots, s_i(n), \ldots, s_N(n)$ of N links.

In signal generator 221, first, a position of peak value point in *power_abs* is calculated and stored in *power_point*. At the same time, set *power_abs (power_point)* = 0 to make it unnecessary to calculate this point when making the next interference. Then, de-spread results of all signals at this point are calculated with the smart antenna algorithm on the *power_point* as is shown with formula (6):

$$S_{ca+1,k}(d) = \sum_{i=1}^{N} h^*_{i,k} \sum_{q=1}^{Q} S_i((d-1)Q+q)C_{q,k}\, pn\_code(l) + S_{ca,k}(d) \qquad (6)$$

where $C_{q,k}$ is a k^{th} user spread spectrum code, $pn\_code(l)$ is a scramble code, $S_{ca,k}(d)$ is an interference cancellation result of the prior time, initial value $S_{0,k}(d) = 0$ and output $S_{ca+1,k}(d)$ is symbolic level. Obviously, as users are not totally synchronized and there are

severe multipath inference and white noise in the system, $S_{ca+1,k}(d)$ is a rough calculation initially.

$S_{ca+1,k}(d)$ is sent to a signal/noise ratio estimating module 224 and signal reconstructing module 222. The function of signal/noise ratio estimating module 224 is to estimate each user signal/noise ratio. The signal generated by signal generator 221 is a de-scrambled, de-spread and demodulated signal. Currently there are many methods to estimate each user signal/noise ratio. One such method is: for a k^{th} user, calculates the power of the signal first, as shown with formula (7):

$$power\_K = \sum_{d=1}^{D} abs^2(S_k(d)) \qquad (7)$$

If the power is greater than a certain field value, then it is an effective power. For all the signals with an effective power, calculate its square difference on a corresponding point of a constellation map. If the square difference is greater than a preset value, then the signal/noise ratio of this user is comparatively low and its $S_{ca+1,k}(d)$ value is unbelievable, so interference cancellation is needed. If, however, the square difference is less than the preset value, then the signal/noise ratio of this user is comparatively high and its $S_{ca+1,k}(d)$ value is believable, so interference cancellation is unneeded. The purpose of using the signal/noise ratio estimating module is to simplify the calculation of interference cancellation, as it is unnecessary to cancel interference for a believable signal.

Signal reconstructing module 222 uses $S_{ca+1,k}(d)$ to reconstruct the original signal, which is chip level and shown with formula (8):

$$S_{ca+1,k}(Q(d-1)+q) = S_{ca+1,k}(d)C_{q,k}pn\_code(l) \qquad (8)$$

Then, the method calculates components of K users on N antennas, as shown with formula (9):

$$S'_{ca+1,i}(n) = \sum_{k=1}^{K} S_{ca+1,k}(n)h^{*}_{i,k} \qquad (9)$$

The recovered results of N antennas are sent to interference cancellation module 223 to cancel the interference, as shown with formula (10):

$$S_i(n) = S_i(n) - S'_{ca+1,i}(n) \qquad (10)$$

In Fig. 2, the function of deciding module 225 is to decide when interference cancellation will be stopped with two deciding conditions: (1) the signal/noise ratio of all signals is greater than the set field value, or (2) the numbers of loops of interference cancellations reaches a set number, which is less than or equal to the length of the search window and within this range the numbers of loops are decided by the processing capability of a digital signal processor, FPGA chip and the like. When either of the two conditions is satisfied, the processing procedure of the interference cancellation method of the smart antenna is ended and the recovered signal $S_{ca+1,k}(d)$ is outputted.

Fig. 3 illustrates 8 antennas ($N = 8$) as an example to explain the processing procedure of the interference cancellation method for smart antennas.

Functional block 301 calculates a channel estimation power by power estimating module 220. Functional blocks 303 and 304 search for a maximum value of power by signal generator module 221, calculate the difference and set the value to 0, de-spread it at its difference point and make beam forming, then the result is sent, at the same time, to a signal/noise ratio decision module 225 and signal reconstructing module 222 (through decision module 225). Functional block 302 sends a synchronized adjustment value $S_s(k)$. Functional block 308 reconstructs the signal and calculates its components on these 8 antennas. Functional block 309 subtracts components on 8 antennas of reconstructed data from the receive_data, stores the result in receive_data, and then functional block 303 to functional block 309 is executed repeatedly. When functional block 305 decides the magnitude of signal/noise ratio by signal/noise ratio decision module 224, and functional block 306 decides, by decision module 225, that the numbers of loops have reached a set value or all users signal/noise ratio has been satisfied, then interference cancellation is ended and functional block 307 outputs the recovered signals.

The invention is particularly useful for CDMA wireless communication systems, including time division duplex (TDD) and frequency division duplex (FDD) CDMA wireless communication systems. One skilled in the art of wireless communication systems, having knowledge of smart antenna principles and digital signal processing, can use method of the invention to design a high-qualified smart antenna system, which can

be used on various mobile communication or wireless user loop systems with high performance.

Many modifications and other embodiments of the invention will come to mind to one skilled in the art to which this invention pertains having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.